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Application of Artificial Neural Networks for the Optimisation of Wetting Contact Angle for Lead Free Bi-Ag Soldering Alloys

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ABSTRACT

In the recent years, electronic packaging provides significant research and development challenges across multiple disciplines such as performance, materials, reliability, thermals and interconnections. New technologies and techniques frequently adopted can be implemented in soldering alloys of semiconductor sectors in terms of optimisation. Wetting contact angle or wettability of solder alloys is one of the important factors which has got the attention of scholars. Hence in this study, due to the remarkable similarity over classical solder alloys (Pb-Sn), Bi-Ag solder was investigated. Data were collected through the effects of aging time variation and different weight percentages of Ag in solder alloys. The contact angle of the alloys with Cu plate was measured by optical microscopy. Artificial neural networks (ANNs) were applied on the measured datasets to develop a numerical model for further simulation. Results of the experiments and simulations showed that the coefficient of determination (R^2) is around 0.97, which signifies that the ANN set up is appropriate for the evaluation.

Keywords: Artificial neural networks, Bi-Ag alloy, lead free soldering alloy, wetting angle

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INTRODUCTION

Producing Pb via the disposal of electronic assemblies is a major threat to the environment (Bath, 2007). In Japan, it is prohibited to dispose Pb in landfills, while disposing it in other sites is severely restricted. In the US, strict rules are going to be passed in Senate and the House of Representatives to save the enviroment against any potential threat of Pb disposal. These rules can be named as (a) H.R. 2922, The Lead Based Paint Hazard Abatement Act of 1991; (b) S. 391, the Lead Exposure Reduction Act of 1991 and (c) H.R. 3554, the Lead Exposure Act of 1992 (Suganuma et al., 2001, pp. 55-64; Matsugi et al., 2011, pp. 753-758). Notably, the possibility of passing these rules is considerbale in the near future. The European Union set 1 July 2006 as the time when "the use of lead, mercury, cadmium, hexavalent chromium and halogenated flame retardants" was banned (Wu et al., 2004, pp. 1-44). This restriction is applied to national and imported/exported products. There are two alternatives for the electronic manufacturers: (1) complete recycling of Pb and (2) using Pb-free solder alloys. The lead-free Bi-Ag soldering alloy is a suitable candidate for high temperature application because it exhibits high melting temperature, similar hardness with respect to Pb-Sn alloy and lower cost compared with Au-Sn (Yamada et al., 2006, pp. 1932-1937; Shimoda et al., 2012, pp. 51-54). The Bi-Ag alloy system also satisfies the requirement of high temperature solder since the solidus temperature is higher than 260°C so that it will not melt (Shimoda et al., 2012, pp. 51-54).

Furthermore, data simulation was done to determine the optimum solutions (Kartalopoulos & Kartapoulos 1997). Artificial neural networks (ANNs) are computatinal techniques which imitate the intelligence of the biological cells to make a decision/response based on the enviroment behaviour/treat. An artificial neural network model contains three layers that include input layer, output layer and a hidden layer which contains nodes or neurons. The developed models deal with non-linear problems for accurate analytical solution (Bhadeshia, 1999, pp. 966-979).

The goal of the current study is to explore the behaviour of various silver weight percentages on the wetting contact angle by conducting simulations using artificial neural network which is one of the most powerful software for simulation and comparison with the experimental results.

MATERIALS AND METHODS

In this research, isothermal aging process was initially conducted on three different compositions of Bi-Ag solder alloys (Bi-1.5Ag, Bi-2.5Ag and Bi-3.5Ag). To do the isothermal ageing process, mechanical convention oven was employed. The samples were heat-treated at 160°C for different periods of 100, 200, 350 and 500 hours (Park et al., 2010, pp. 4900-4910). Wetting angle was measured via optical microscope at the magnification of 20X for at least 4 samples for each of the selected alloys. The wetting angle was determined via cross-sectional angle at the location where the edge of the solder layer intersects with the pad of the substrate. The wetting angle of the Bi-Ag bulk solder was determined according to the measured angles determined by the optical microscope. Subsequently, artificial neural network, developed by Matlab software (R2011a), was used to study the behaviour of contact angles.

RESULTS AND DISCUSSION

Expert neural classifier executes high efficient learning for faster convergence of data (Demuth & Baele, 2000). In the current project, data of the microscopical study of the wetting angle of selected alloys were introduced as the input of the neural network database in order to develop a neural network model for a better material selection, as shown in Figure 1 below.

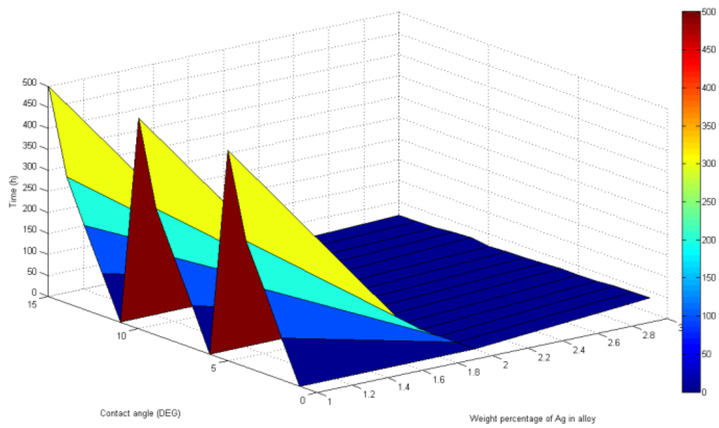

Figure 1. Comparison of the Isothermal Aging time of Ag contents and contact angles

As stated previously, a neural network model generally contains three layers. The first layer is called the input layer. In this layer, the input variables and their values for all the observations / measurements are introduced to the neural network model (Ham & Kostanic, 2000). In the current study, these inputs are aging time, aging temperature and weight percentage of silver. The next layer is the hidden layer that makes a connection between the input layer and the third layer called the output layer. From the mathematical point of view, the hidden layer contains very flexible functions (e.g., hyperbolic tangent function) to capture the intrinsic nature of the input database and correlate it to the output database. The output of the develped model would be the prediction of wetting angle with a smaller error.

The neural network model was developed based on the acquired dataset for the studied alloys. As shown Figure 2, the training process was done when validation check reached three. The epoch value of zero iterations and the performance (measured via mse) of 3.4 e^{-17}, gradient decent value of 1.1 e^{-7} and mu value of 1.0 e^{-6}.

Figure 2 depicts the fact that there is a very small difference between the test curve and validation curve. Therefore, it can be said that they are somehow simillar. This fact reveals that there is no considerable problem with the training step of the constructed model. Altough the training procedure was continued up to three epochs, the best performance validation was obtained at epoch 0, with the value equivalent to 32.9748.

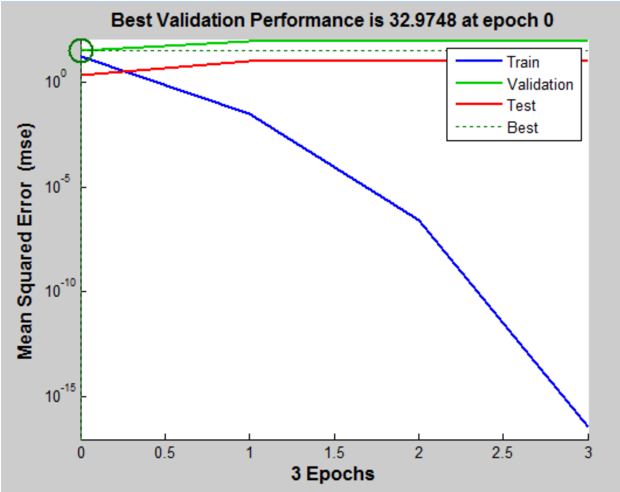

Figure 2. Postprocessing plots to analyse the performance of the developed neural network model

Artificial neural network can be used as a classifier for the Bi-Ag contact angle. Achived data are shown in Figure 3. Regardless of the size of the material database, the neural network can be implemented as a classifier for the studied system.

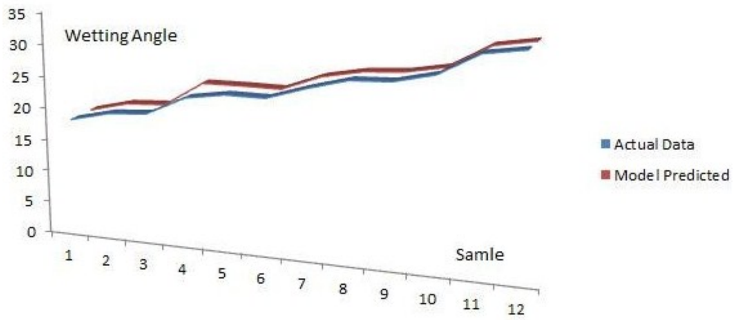

Figure 3. The actual data and model predicted data

The experimental data and the test result data were also processed through statistical software using Matlab to determine coefficient of determination (R^2) (Mousavifard et al., 2015, pp. 315-324). The result confirms ($R^2 \approx 0.97$) the findings obtained by ANNs and lab experiment which have an acceptable deviation. Figure 4 presents further information on the statistical analysis.

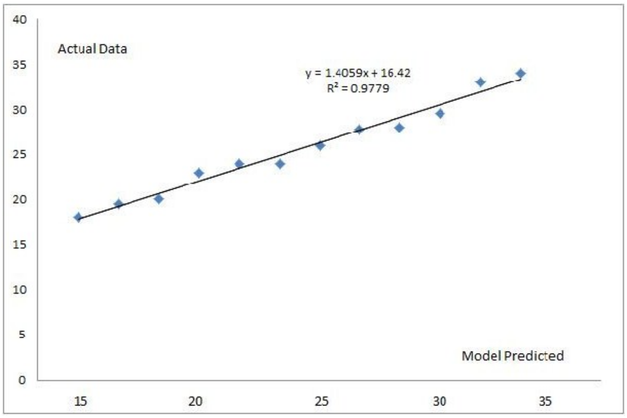

Figure 4. The scatter plots of the ANNs model predicted versus actual values for all data sets

CONCLUSION

This work presents the application of artificial neural networks to predict and optimise the contact angle of lead-free soldering alloys. In the future, the system can be extended to all sorts of soldering alloy with more complicated conditions. Basically, ANNs can handle a huge dataset. The ANN model shows the best results and the classification accuracy was around 0.97%. Based on the results of the current study, it can be said that the application of artificial neural network may lead to better material selections and designs in the future.

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